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Title:	What is ENDF and NJOY? And why should I care?
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NNSA
National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

What is ENDF and NJOY?

And why should I care?

Wim Haeck, XCP-5

March 19, 2018

National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Not one but three questions …

March 19, 2018

12-1 pm

TA03, Library, JRO1+2

- **What is ENDF?**
- **What is NJOY?**
- **And why should I care?**

- **But I guess I will create even more …**

What is ENDF?

What is ENDF?

Easy answer: it's an acronym

ENDF = Evaluated Nuclear Data File/Format

Wait a minute, now I have more questions …

- What is nuclear data?
- What does evaluated mean?
- Why distinguish File and Format?

What is nuclear data?

Nuclear data is everything we need to describe particle transport and nuclear processes

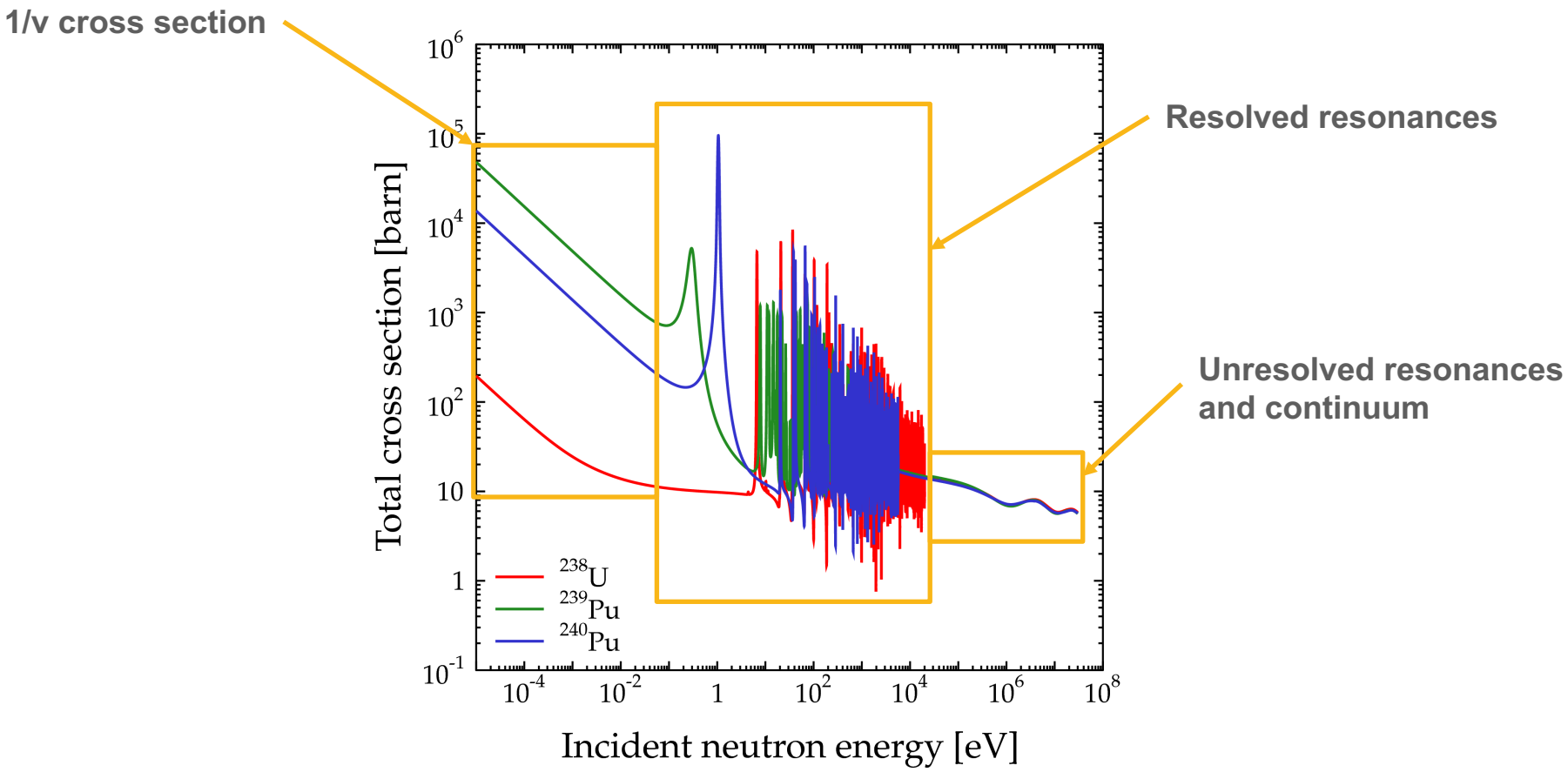
- Nuclear reaction data
  - Cross sections, secondary particle angular distributions, etc.
- Radioactive decay data
- Uncertainties (covariance data)

Used by particle simulation codes at LANL

- Monte Carlo particle transport with MCNP
- Deterministic particle transport with PARTISN
- Material irradiation with CINDER

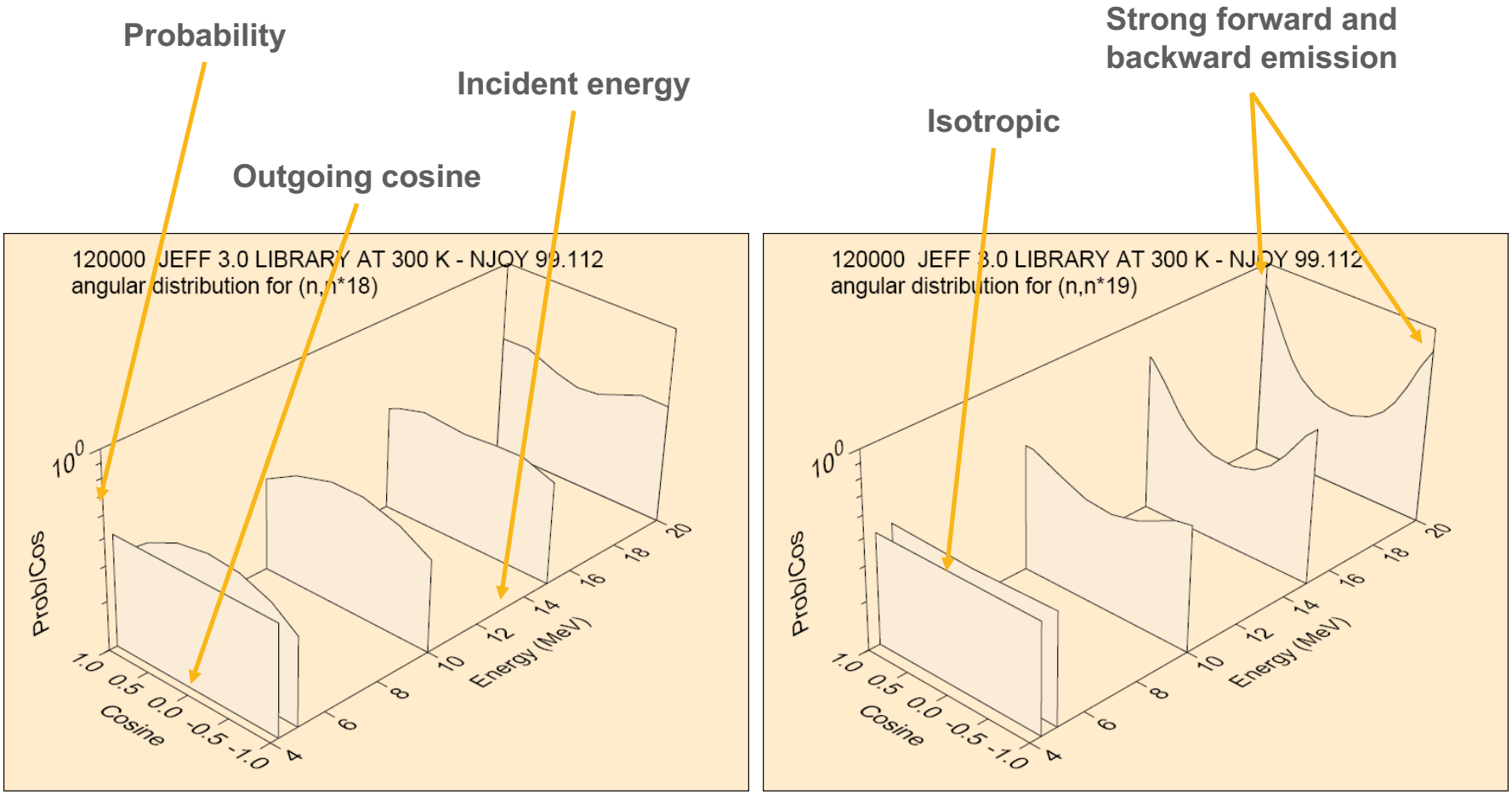
What is a cross section?

A cross section gives reaction probability



What is an angular distribution?

It gives the direction of the outgoing particle

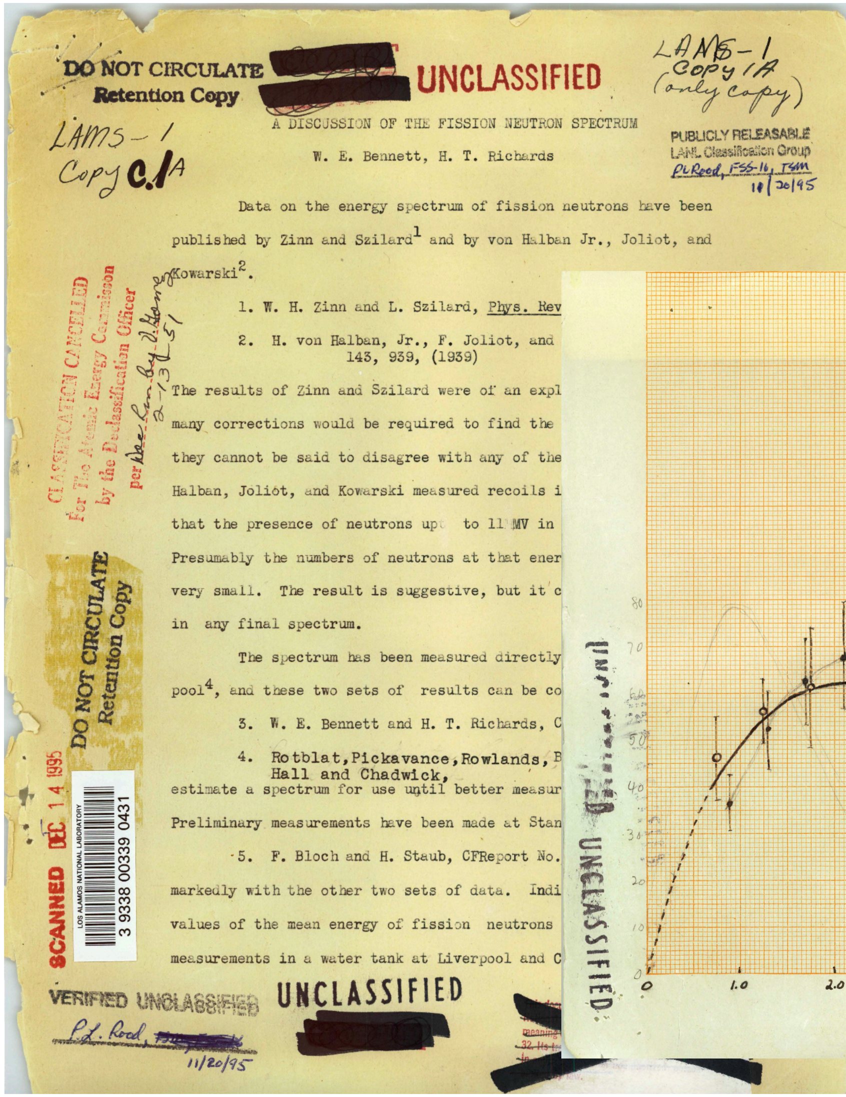


What does evaluated mean?

Evaluation is combining experimental data and nuclear interaction theory to provide the best available data and uncertainty in a common energy range

Maybe we need a “What is it, nuclear data evaluation?”

Can you give an example?



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A DISCUSSION OF THE FISSION NEUTRON SPECTRUM

W. E. Bennett, H. T. Richards

Data on the energy spectrum of fission neutrons have been published by Zinn and Szilard[1] and by von Halban Jr., Joliot, and Kowarski[2].

1. W. H. Zinn and L. Szilard, Phys. Rev

2. H. von Halban, Jr., F. Joliot, and 143, 939, (1939)

The results of Zinn and Szilard were of an expl many corrections would be required to find the they cannot be said to disagree with any of the Halban, Joliot, and Kowarski measured recoils i that the presence of neutrons up to 11 MV in Presumably the numbers of neutrons at that ener very small. The result is suggestive, but it c in any final spectrum.

The spectrum has been measured directly pool[4], and these two sets of results can be co

3. W. E. Bennett and H. T. Richards, C

4. Rotblat, Pickavance, Rowlands, B Hall and Chadwick,

estimate a spectrum for use until better measur

Preliminary measurements have been made at Stan

5. F. Bloch and H. Staub, CFReport No.

markedly with the other two sets of data. Indi values of the mean energy of fission neutrons measurements in a water tank at Liverpool and C

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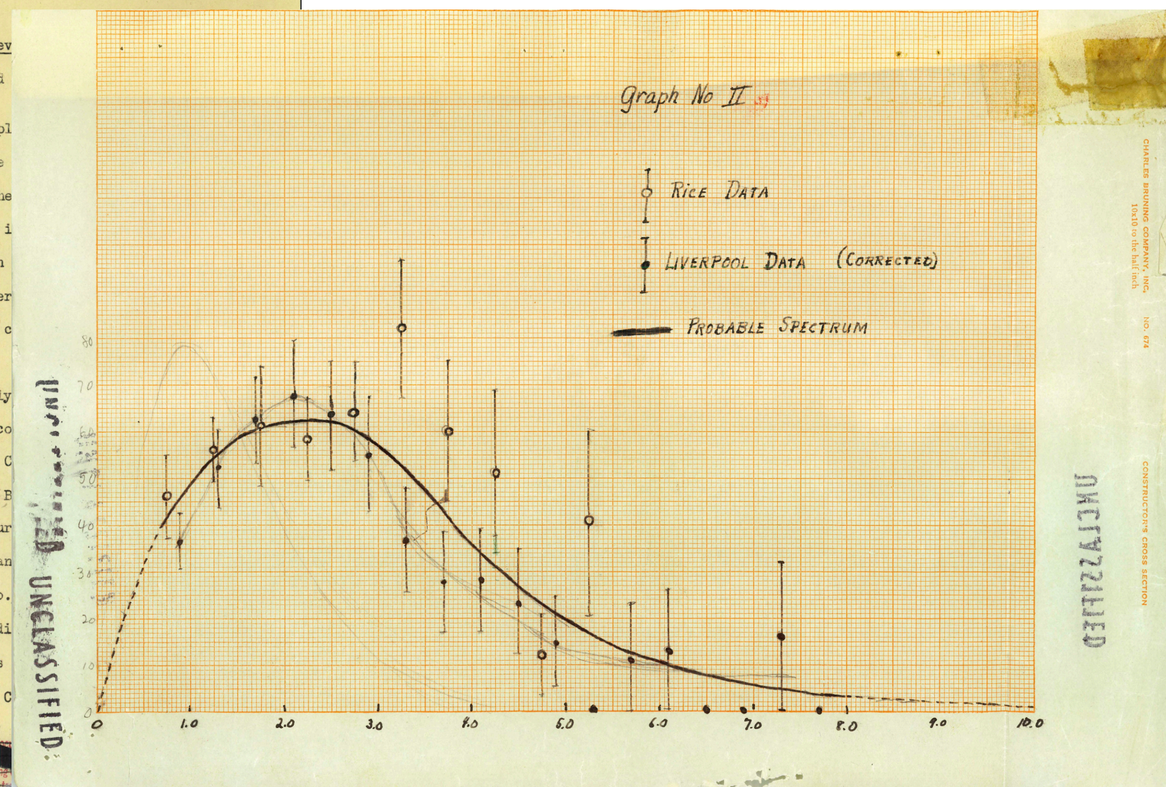


I give you LA-00001-MS

- June 28, 1943 (!)

Why distinguish File and Format?

ENDF = Evaluated Nuclear Data File/Format

Evaluated Nuclear Data Format

- Format specification for storing/organising nuclear data
- Format versions are designated with an Arabic number
  - ENDF-6 is the current format version

Evaluated Nuclear Data File

- The name of the US nuclear data library
- Library versions are designated with a Roman numeral
  - ENDF/B-VIII.0 is the latest version, released in February 2018

Where does it come from?

ENDF was created in the mid-1960s

- The format has gone through 6 iterations
- Used for 8 generations of the ENDF/B library
  - ENDF/B-I in July 1968
  - ENDF/B-VIII.0 in February 2018

ENDF is developed and maintained by the NNDC and coordinated by CSEWG

- NNDC: National Nuclear Data Centre at BNL
- CSEWG: Cross Section Evaluation Working Group
  - Collaboration between national labs, universities and nuclear industry from the US and Canada

Does anybody else use it?

The ENDF format is the de facto standard for all nuclear data libraries in the world.

There are multiple "independent" libraries

- Europe: Joint European Fission and Fusion (JEFF)
- Japan: Japanese Evaluated Nuclear Data Library (JENDL)
- China: Chinese Evaluated Nuclear Data Library (CENDL)
- Russia: BROND
- All libraries are freely available from different nuclear data centres (OECD/NEA, IAEA/NDS, BNL/NNDC)

What does it look like?

```
9.223500+4 2.330248+2          0          0          0          09228 3 18     1
1.934054+8 1.934054+8          0          0          1        8399228 3 18     2
       839          2                                              9228 3 18     3
1.000000-5 0.00000+00 2.250000+3 0.00000+00 2.250000+3 2.634378+09228 3 18     4
2.250014+3 2.668097+0 2.250056+3 2.769988+0 2.250112+3 2.907176+09228 3 18     5
2.250251+3 3.252747+0 2.250307+3 3.389935+0 2.250363+3 3.525523+09228 3 18     6
2.250419+3 3.658711+0 2.250470+3 3.778100+0 2.250517+3 3.884190+09228 3 18     7
2.250563+3 3.987480+0 2.250598+3 4.063173+0 2.250633+3 4.136965+09228 3 18     8
2.250668+3 4.209058+0 2.250703+3 4.279151+0 2.250738+3 4.347343+09228 3 18     9
2.250772+3 4.413436+0 2.250807+3 4.477529+0 2.250842+3 4.539621+09228 3 18    10
```

If you can read this, you are ready to join the nuclear data team. Send an email to nucldata@lanl.gov to apply.

How is it structured?

An ENDF library has multiple sub-libraries

- Incident particle data: n, p, d, t, ^{3}He, α
- Thermal scattering data for crystals and molecules
- Radioactive decay data
- Neutron induced and spontaneous fission yields

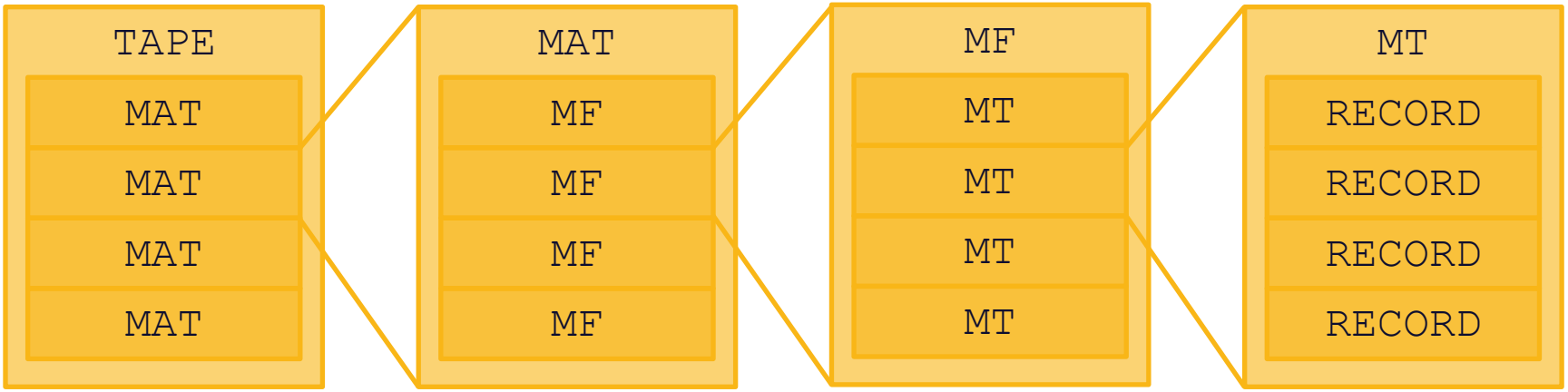
Each sub-library is physically separated and stored in one or more “tapes”

- ENDF jargon dating back to the time of magnetic tapes

How is it structured?

Each tape is structured as a sequence

- Materials designated by the `MAT` number
- Files designated by the `MF` number
- Sections designated by the `MT` number
- A section is a sequence of records



How is it structured?

A material is identified by its `MAT` number

- A specific nuclide, an element, a molecule, etc.
- Between `1` and `9999`
- General rules for isotopes
  - `Z * 100 + 25` for the first stable isotope
  - Decremented/incremented for the previous/next isotope
  - Numbers in between for metastable states

- For example:
  - `125` for H1, `9228` for U235
  - `9546` for Am242, `9547` for Am242m

How is it structured?

Files identified by their `MF` number store specific types of data:

- `MF1`: descriptive and miscellaneous data
- `MF2`: resonance parameters
- `MF3`: cross section data
- `MF4`: secondary particle angular distribution
- `MF5`: secondary particle energy distribution
- `MF6`: correlated secondary particle angle-energy distribution
- `MF31` to `MF35`: covariance data
- And there are even more …

How is it structured?

Sections designated by an `MT` number store specific "reaction data"

- These can be "simple" reactions
  - `MT102` (neutron capture), `MT51` to `MT91` (inelastic levels)
- These can be "summation" reactions
  - `MT4` (inelastic scattering, sum of `MT51` to `MT91`)
- These can be "special" sections
  - `MT451` (descriptive data, only in `MF1`)
  - `MT151` (resonance parameters, only in `MF2`)

- `MT` numbers are limited to `1-999`

How is it structured?

Only 6 record types to store information:

- `TEXT`: stores just text
- `CONT`: 2 floating point numbers and 4 integers
- `LIST`: a list of values
- `TAB1`: a one dimensional function y = f(x)
- `TAB2`: a two dimensional function z = f(x,y), used in combination with multiple TAB1 records
- `INTG`: a correlation matrix (used for covariance data)

Special cases:

- `HEAD`: a `CONT` record at the beginning of each section
- `TEND`, `MEND`, `FEND`, `SEND`: records to signal the end of a tape, material, file and section

What does it look like?

Let's look at that again …

```
 9.223500+4 2.330248+2          0          0          0          09228 3 18    1
 1.934054+8 1.934054+8          0          0          1        8399228 3 18    2
        839          2                                              9228 3 18    3
 1.000000-5 0.00000+00 2.250000+3 0.00000+00 2.250000+3 2.634378+09228 3 18    4
 2.250014+3 2.668097+0 2.250056+3 2.769988+0 2.250112+3 2.907176+09228 3 18    5
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 2.250668+3 4.209058+0 2.250703+3 4.279151+0 2.250738+3 4.347343+09228 3 18    9
 2.250772+3 4.413436+0 2.250807+3 4.477529+0 2.250842+3 4.539621+09228 3 18   10
```

Lines consisting of 80 characters

- Six 11 characters columns for floats and integers
- Four columns for the MAT, MF, MT and sequence number

Isn’t there anything better?

ENDF’s structure is deceptively simple to understand but its content is extremely hard to master

GNDS = Generalised Nuclear Data Structure

- Initially developed at LLNL to replace ENDL
- Now an international collaboration through OECD/NEA
  - WPEC SG38, WPEC EG-GNDS, WPEC SG43
- A more physical approach to storing data
- This should eventually replace ENDF

What is NJOY?

What is NJOY?

Easy answer: it used to be an acronym …

Multigroup Interpretation of Nuclear X sections

What do you mean: that's MINX, not NJOY?

40 years ago, there was this printer failure …

- M + 1 = N
- I + 1 = J
- N + 1 = O
- X + 1 = Y

What is NJOY?

It is LANL's nuclear data processing software

Initially developed in the '70s as a single package to replace all of LANL's previous tools

- Originally written in Fortran-77
- Known as MINX-II prior to the printer malfunction
- MINX: Multi-group Interpretation of Nuclear X sections
- LAPHAN0 for photon production
- GAMLEG for photon interaction data
- ETOPL for MCN (MCNP predecessor) libraries

What is NJOY?

NJOY was first released in 1977

- Last major releases in ‘99, 2012 and 2016
- NJOY evolves because ENDF evolves
- Still developed in Fortran …

NJOY2016.29 is the latest version

- It is now open source software
- Available from https://github.com/njoy/NJOY2016

Similar tools exist

- AMPX (ORNL), PREPRO (IAEA), Fudge (LLNL), etc.

What does it do?

NJOY provides a set of data processing modules that can be called sequentially

- RECONR: reconstruct and linearise cross section data
- BROADR: temperature dependent cross sections
- GROUPR: multi-group cross sections
- HEATR: calculate KERMA and DPA cross sections
- THERMR: thermal scattering data
- GASPR: charged particle production cross sections
- ACER: produce ACE libraries for MCNP
- PLOTR & VIEWR: visualisation of nuclear data

And there are many more modules …

What does it look like?

```
moder
20 -25
reconr
-25 -21
'AM241 - 293.6 K - JENDL 4.0 (NJOY 99.259)'/
9543 0 0
0.001 0 0.01 5e-08
0 /
broadr
-25 -21 -22
9543 1 0 0 0
0.001 1e+06 0.01 5e-08
293.6
0 /
heatr
-25 -22 -21 /
9543 5 0 0 0 0 /
302 318 402 442 444 /
thermr
0 -21 -22 /
0 9543 16 1 1 0 1 221 2 /
293.6
0.001 5.0
gaspr
-25 -22 -21  /
```

```
unresr
-25 -21 -22
9543 1 9 1
293.6
1e+10 1e+8 1e+6 1e+4 1e+3 3e+2 1e+2 3e+1 1e+1
0 /
purr
-25 -22 -21
9543 1 9 20 64 1 0
293.6
1e+10 1e+8 1e+6 1e+4 1e+3 3e+2 1e+2 3e+1 1e+1
0 /
acer
-25 -21 0 40 41
1 0 1 .02 /
'AM241 - 293.6 K - JENDL 4.0 (NJOY 99.259)'/
9543 293.6
1 1
/
acer
0 40 42 40 41
7 1 1 -1 /
'AM241 - 293.6 K - JENDL 4.0 (NJOY 99.259)'/
stop
```

Isn’t there anything better?

NJOY21, NJOY for the 21st century

- Complete, ground-up rewrite of NJOY
- Modernization of code base
- Written in C++ using latest programming techniques
- Verified and validated
- Backwards compatible with NJOY2016

For more information:

- https://njoy.github.io/NJOY21
- https://github.com/njoy

Isn’t there anything better?

Main goals for NJOY21

- Maintain NJOY’s image of a trusted and stable processing code
  - Every function and feature is automatically, frequently, and regularly tested
  - Every feature of NJOY will be documented
- Easier to build, verify and validate, interact, process
- More flexible
- Faster
- More maintainable

And why should I care?

And why should I care?

Nuclear data has its uses …